method for producing a virtually stained digital holographic microscopy (DHM) image. The method includes receiving a first training data set comprising DHM images of individual white blood cells and a second training data set comprising images of actually stained white blood cells, wherein the images in the first training data set are not paired with the images in the second training data set. The method also includes applying a learning process which uses generative adversarial networks to the first training data set and the second training data set to generate an image conversion algorithm. The method further includes receiving a DHM image, applying the image conversion algorithm to the DHM image to produce the virtually stained DHM image, and displaying the virtually stained DHM image through a graphical user interface.

[0012] In yet another aspect, embodiments of the present disclosure are directed to a cell visualization system configured to produce virtually stained digital holographic microscopy (DHM) images. The cell visualization system includes a virtual staining device configured to receive a DHM image of one or more cells and apply an image conversion algorithm to the DHM image to produce the virtually stained DHM image, where the image conversion algorithm was generated using unpaired data sets.

[0013] Additional features and advantages of the invention will be made apparent from the following detailed description of illustrative embodiments that proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The foregoing and other aspects of the present invention are best understood from the following detailed description when read in connection with the accompanying drawings. For the purpose of illustrating the invention, there are shown in the drawings embodiments that are presently preferred, it being understood, however, that the invention is not limited to the specific instrumentalities disclosed. Included in the drawings are the following Figures:

[0015] FIG. **1** is an example schematic of off-axis digital holographic microscopy system with a reference beam created from an object beam;

[0016] FIG. **2** shows example images of stained white blood cells;

[0017] FIG. **3** shows example DHM images of white blood cells;

[0018] FIGS. **4**A-**4**B show an exemplary cell visualization system, consistent with disclosed embodiments;

[0019] FIGS. **5**A-**5**F show a comparison of images of actually stained white blood cells and virtually stained white blood cells; and

[0020] FIG. **6** illustrates an exemplary computing environment within which embodiments of the invention may be implemented.

DETAILED DESCRIPTION

[0021] The present disclosure describes embodiments of apparatuses, systems, and associated methods related to cell visualization using virtual staining of DHM images. In some embodiments, a cell visualization system is configured to receive a blood sample and produce DHM images of cells within the sample, including white blood cells. The cell visualization system may be configured to identify the type of each white blood cell and modify the associated DHM image such that each white blood cell is colorized to imitate what the cell might look like using manual staining and microscopy.

[0022] Consistent with disclosed embodiments, the cell visualization system may be trained to classify white blood cells using deep learning algorithms which utilize unpaired data samples. For example, generative adversarial networks with cycle consistency may be used to train the cell visualization system to learn how to identify different types of white blood cells in DHM images and how to colorize the images in order for the white blood cells to appear as if they had been stained in a comparable manual process.

[0023] FIG. **4**A is a diagram of a cell visualization system **100**, according to a disclosed embodiment. The cell visualization system **100** includes a DHM device **110**, a training device **120**, and a virtual staining device **130**. The cell visualization system **100** is configured to produce DHM images which are virtually stained to imitate the appearance of cells which have been manually stained and viewed under a conventional microscope (e.g., the images in FIG. **2**). FIG. **2** further depicts an exemplary flow of data through the cell visualization system **100** in order to produce the virtually stained DHM images.

[0024] Each of the DHM device **110**, the training device **120**, and virtual staining device **130** may be separate or may be selectively integrated into a combined device. The DHM device **110** includes DHM components known in the art and configured to produce DHM images based on a received blood sample. The training device **120** is configured to receive DHM images and training data, and execute a training process which results in a trained image conversion process. The virtual staining device **130** is configured to receive and execute the trained image conversion process in order to convert DHM images received from the DHM device **110** into virtually stained images. The virtual staining device **130** may be further configured to display the virtually stained images to a user (e.g., a clinician) for review.

[0025] FIG. **4**B is a schematic diagram of an exemplary process flow through the cell visualization system **100**. The DHM device **110** is configured to produce DHM images of cells, such as those shown in FIG. **3**. For example, the DHM device **110** may receive a blood sample and capture periodic data using off-axis DHM while the sample is flowing. The captured data may be converted into DHM images which encompass many cells, including red and white blood cells. These capture images which include many cells may be generally referred to as raw DHM images. In some embodiments, the DHM device **110** is configured to pre-process the raw DHM images in order to separate the raw data into separate images of one or more cells. For example, the DHM device **110** may look for bright spots within the raw DHM images and perform an analysis to identify which of the bright spots are above a size or other classifier threshold in order to identify which of the spots are cells. Each of the classified cells may be transformed into a separate DHM image, resulting in separate cell images such as those shown in FIG. **3**.

[0026] The training device **120** is configured to receive image data through one or more I/O devices, including an I/O device connected to the DHM device. The training device **120** is also configured to receive training data in the form of other images, which are not DHM images (i.e., images of stained samples) through I/O device(s). The training data may be provided by a different imaging device,